SCOPE AND SCALE EFFICIENCY GAINS DUE TO VERTICAL INTEGRATION IN THE U.S. HOG SECTOR

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ABSTRACT

Using a non-parametric linear programming approach, our contribution is (1) to examine if efficiency gains in hog production are realized due to vertical integration and (2) to demonstrate the efficiency gains that are realized are a product of economies of scope and scale. The model uses U.S. hog sector data for the period, 1982-1997. Results indicate efficiency gains are realized due to vertical integration and can be explained by scope and scale efficiency gains. The t-test at the 5% level of significance indicates the mean overall efficiency gains; scope efficiency gains and scale efficiency gains are significantly different from one.

JEL classification: O3, C6, Q1.

Keywords: Nonparametric linear programming approach, Vertical integration, Scale, Scope, Efficiency gains, U.S. Hog sector.

SCOPE AND SCALE EFFICIENCY GAINS DUE TO VERTICAL INTEGRATION IN THE U.S. HOG SECTOR

Vertical integration of the production stages of any sector emerges whenever there are economic efficiency advantages over specialized non-vertically linked production. However, technological advances leading to structural changes[1] in crop and livestock agriculture appear to have been directed toward horizontal or non-vertical integration. This has been particularly the case in the livestock sector, more specifically with the hog industry. The reasons for these changes are not clear in that economic studies have shown little size economies within production stages. Currently beginning farmers tend to concentrate on a particular production stage of the livestock production. In general there may well be a lack of understanding of the existing advantages of integrated operations in the livestock sector particularly vertical integration of production stages.

For traditional agricultural production firms, the reluctance to develop vertical production linkages may occur because of lack of management ability for additional production activities, greater economic advantages of horizontal integration, lack of capital or other factors. These rigidities are not nearly as limiting for cooperatives and corporations. Hence, there is increasing interest in the vertical integration, which has recently been observed in cattle, hog, and poultry production. The increasing vertical

[1] See Hallam (1993) , Gardner and Pope (1978), Kislev and Peterson (1982 and 1996), Huffman and Evenson (1997) for research on structural changes with respect to farm size, farm specialization, off-farm wages, input price changes, technical, efficiency and productivity.

linkages in these industries have led to concerns over reduced competition (current or future). Conversely, if such integration is caused by significant economic efficiency gains, the setting becomes one of efficiency versus concern over control of all components of a particular industry.

Examination of the structural changes resulting from technological determinants in the industry producing a single output in the production chain (more than one output in the production chain) can be identified with economies of scale (scope). Considerable literature [Panzar and Willig (1981); Eaton and Lemche (1991); and Lawrence and Braunstein (1992); Christensen and Greene (1976); Panzar and Willig (1977); Lawrence (1989); Cohn et al (1989)] has been directed towards the analysis of economies of scope due to vertical integration with very little attention direction directed towards vertical integration. Economies of scope exist if $C(y_1, y_2) < C(y_1, 0) + C(0, y_2)$ where $C(y_1, y_2)$ is the industry's cost of all production stages, i.e., output 1 in stage one and output 2 in stage two given input prices. Others have addressed economies of scale due to output expansion for each production stage. The overall scale economies (or ray economies of scale) exist if $C(y_1, y_2) / \sum_i y_i C_i(y_1, y_2)$ is greater than one, where $C_i(y_1, y_2)$ is the marginal cost of producing the i^{th} output. The estimation of economies of scope and scale across production stages within a sector describes integration.

An alternative to the econometric estimation of economies of scope and scale is the use of non-parametric linear programming approach. In recent times, the programming approach[2] of measuring efficiency in public and private sectors has received renewed attention. Data Envelopment Analysis (DEA) has certain advantages, in that it does not impose a priori functional form, can handle multi-outputs and multi-inputs, and compute efficiency without the need of output and input prices. A vast majority of DEA models use only quantity (quantity and price) data and calculate direct primal (indirect dual) measures. Fare (1986), and Fare and Primont (1988) have proposed the estimation of diversification efficiency gains identified with economies of scope invoking the duality equivalency between the subadditivity $C(\sum_{k=1}^{K} Y^k, w) \leq \sum_{k=1}^{K} C(Y^k, w)$ of the cost function for input prices (w) and the superadditivity $L(\sum_{k=1}^{K} Y^k) \supseteq \sum_{k=1}^{K} L(Y^k)$ of the input requirement set. Extending the work of Fare and Primont, utilizing the duality equivalency between the cost function and the input requirement set, and the decomposition of the technical efficiency into pure technical efficiency and scale efficiency, we (1) examine if efficiency gains in the U.S. hog industry are realized through vertical integration and (2) demonstrate if these efficiency gains results from economies of scope, economies of scale or both employing

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[2] The non-parametric programming approach to the study of efficiency has had a relatively short history in agriculture sector, know familiarly know as Data Envelopment Analysis (DEA). M.J. Farrell (1957) discussed the empirical estimation of efficiency for multiple outputs and multiple inputs. The application made was to U.S. agriculture. Farrell and Fieldhouse (1962) published another analysis using farm survey data. In 1966 at the Western Farm Management Association four papers were presented (Bressler, Boles, Seitz, and Sitorus) related to issues of different components of efficiency and their measurement. In 1978 DEA was introduced by Charnes et al and popularized in a more informative and easily applied way by Fare et al (1994). Lovell (1993) presented a selective overview of the existing techniques and models to estimate productive efficiency.

farrow-to-feeder, feeder-to-finish, and farrow-to-finish output and input data from 1982-1997 for the U.S. hog sector.

NONPARAMETRIC PROGRAMMING MODEL FOR SCOPE AND SCALE GAINS

Let an industry with ***k*** specialized firms engage in production of ***k*** unique products over time ***t*** with vector of inputs x_i. The input requirement set transforming I-dimensional vector of inputs $x_{i,t}^k \in \Re_+$ into a vector of output $y_t^k \in \Re_+$ is represented by input set for firm ***k***:

$$\text{(1)} \quad L(Y^k) = \{x : zY^k \geq y_t^k, \sum_{i=1}^{I} zX^k \leq x_{i,t}^k, z \geq 0\}$$
$$t = 1,.....,\text{T} \quad i = 1,.....\text{I}$$

where z is a nonnegative and $z \geq 0$ indicates constant return to scale assumption, I and T is the input vector and the length of the time series respectively.

The input set for sum of ***k*** individual specialized firms can be represented as:

$$\text{(2)} \quad \sum_{k=1}^{K} L(Y^k) = \{ x : \sum_{k=1}^{K} zY^k \geq y_t^k, \sum_{k=1}^{K}\sum_{i=1}^{I} zX^k \leq x_{i,t}^k, z \geq 0 \}$$
$$t = 1,.....,\text{T} \quad i = 1,.....\text{I} \quad k = 1,.....\text{K}$$

where I, T and K is the identical input vector in each of the ***k*** firms, length of the time series, number of specialized firms engaged in production of ***k*** unique products respectively, and $z \geq 0$ indicates constant return to scale assumption.

Instead of identical input vectors for each of the ***k*** firms, the vertically integrated firm produces ***k*** unique products with set of I non-allocable input vector. The production technology of combined ***k*** firms (vertically integrated firm) utilizing the same variables in equation (2) with the exception of input vector is represented by an input set as:

$$(3) \quad L(\sum_{k=1}^{K} Y^k) = \{\, x: \sum_{k=1}^{K} zY^k \geq y_t^k \,, \sum_{i=1}^{I} zX \leq x_{i,t} \,, z \geq 0 \,\}$$
$$t = 1,.....,\mathrm{T} \quad i = 1,.....\mathrm{I} \quad k = 1,.....\mathrm{K}$$

where the definitions are similar to those defined for equation (2) above.

The vertical integration efficiency gains is computed by comparing the frontiers of ***k*** individual specialized firms $\sum_{k=1}^{K} L(Y^k)$ and vertically integrated firm (combined ***k*** firms) $L(\sum_{k=1}^{K} Y^k)$ under constant returns to scale assumption as:

$$(4) \quad \text{Vertical Integration Efficiency gains } = \sum_{k=1}^{K} L(Y^k) \Big/ L(\sum_{k=1}^{K} Y^k)$$

where the ratio great (equal to) than one indicates efficiency (no efficiency) gains due to vertical integration.

The concept of input set can be represented by the input distance function for firm ***k*** as:

$$(5) \quad D_i(y_t, x_{i,t})^{-1} = \min_{\lambda,z} \lambda \ \{\lambda : (y_t, \lambda x_{i,t}) \in L(Y)\}$$

or

$$\min_{\lambda,z} \lambda \quad s.t. \quad y_t \leq zY \qquad ,$$
$$\sum_{i=1}^{I} \lambda x_{i,t} \geq zX_i \qquad i = 1,.....,I$$
$$z \geq 0 \ or \ (z = 1)$$

sum of ***k*** individual specialized firms as:

$$(6) \qquad D_i^S(y_t^k,\, x_{i,t}^k)^{-1} = \min_{\lambda,z} \lambda \ \{\lambda : (y_t^k, \lambda\, x_{i,t}^k) \in \sum_{k=1}^{K} L(Y^k)\}$$

or

$$\min_{\lambda,z} \lambda \quad s.t. \quad \sum_{k=1}^{K} y_t^k \le z\,Y^k \qquad k = 1,\ldots..,K$$

$$\sum_{k=1}^{K}\sum_{i=1}^{I} \lambda\, x_{i,t}^k \ \ge\ z\,X_i^k \qquad i = 1,\ldots..,I$$

$$z \ \ge 0 \ \ or \ \ (z = 1)$$

and vertically integrated firm as:

$$(7) \qquad D_i^V(y_t^k,\, x_{i,t})^{-1} = \min_{\lambda,z} \lambda \ \{\lambda : (y_t^k, \lambda\, x_{i,t}) \in L(\sum_{k=1}^{K} Y^k)\}$$

or

$$\min_{\lambda,z} \lambda \quad s.t. \quad \sum_{k=1}^{K} y_t^k \le z\,Y^k \qquad k = 1,\ldots..,K$$

$$\sum_{i=1}^{I} \lambda\, x_{i,t} \ge\ z\,X_i \qquad i = 1,\ldots..,I$$

$$z \ \ge 0 \ \ or \ \ (z = 1)$$

where $D_i^S()\ and\ D_i^V()$ is the input distance function for ***k*** specialized firms and vertically integrated firm respectively. The intensity variable $z \ge 0$ describes the constant returns to scale (CRS) technology and $z = 0$ describes the variable return to scale (VRS) technology. The scale efficiency can be computed for ***k*** specialized firms and vertically integrated firm as the ratio of input distance functions under the assumption of constant returns to scale and variable returns to scale technology as:

$$(8) \qquad S_i^S(y,x) = \frac{D_i^S(y,x|_{CRS})}{D_i^S(y,x|_{VRS})}$$

$$S_i^V(y,x) = \frac{D_i^V(y,x|_{CRS})}{D_i^V(y,x|_{VRS})}$$

where $S_i^S() \, and \; S_i^V()$ is the scale efficiency for ***k*** specialized firms and vertically integrated firm respectively.

Utilizing the decomposition of technical efficiency into pure technical efficiency and scale efficiency by Farrell, the vertical integration efficiency gains can be defined as a product of economies of scope efficiency gains (due to pure technical efficiency) and economies of scale efficiency gains (due to scale efficiency). The vertical integration efficiency gains defined as a product of scope and scale can be represented by input distance functions as:

$$(9) \qquad \frac{\sum_{k=1}^{K} L(Y^k)}{L(\sum_{k=1}^{K} Y^k)} \equiv \frac{D_i^S(y,x|_{CRS})}{D_i^V(y,x|_{CRS})} = \frac{D_i^S(y,x|_{VRS})}{D_i^V(y,x|_{VRS})} * \frac{S_i^S(y,x)}{S_i^V(y,x)}$$

$$\text{Vertical Integration Efficiency gains} = \text{Scope gains} * \text{Scale gains}$$

where D_i is the input distance function, CRS is the constant returns to scale, VRS is variable returns to scale, S_i is the scale efficiency, and superscript ***S*** is sum of ***k*** specialized firms, ***V*** is vertically integrated firm. The first part on the right hand side represents efficiency gains due to scope (as in Fare 1986, 1988) with the second part ascribed to efficiency gains due to scale. Hence, overall efficiency gains can be attributed to scope and scale efficiency gains.

The measure of overall, scope and scale efficiency gains is graphically represented in Figure (1). In Figure 1, the firm's CRS and VRS technology for specialized and vertically integrated technology is represented as $CRS^S \; and \; VRS^S$ and

CRS^V *and* VRS^V respectively. Based on Figure 1, the input based scope efficiency gains (first part of equation 9) due to vertical integration can be represented:

(10) Scope Efficiency gains $= \dfrac{D_i^S(y, x|_{VRS})}{D_i^V(y, x|_{VRS})} = \dfrac{OX/OX_S}{OX/OX_V} = \dfrac{OX_V}{OX_S}$

The input based scale efficiency gains (second part of equation 9) due to vertical integration can be represented as:

(11) Scale Efficiency gains $= \dfrac{S_i^S(y, x)}{S_i^V(y, x)} = \dfrac{\dfrac{OX/OX^{F_S}}{OX/OX_S}}{\dfrac{OX/OX^{F_V}}{OX/OX_V}} = \dfrac{OX_S/OX^{F_S}}{OX_V/OX^{F_V}}$

and the input based vertical integration efficiency gains can be represented as:

(12) $\dfrac{D_i^S(y, x|_{CRS})}{D_i^V(y, x|_{CRS})} = \dfrac{OX_V}{OX_S} * \dfrac{OX_S/OX^{F_S}}{OX_V/OX^{F_V}} \equiv \dfrac{OX^{F_V}}{OX^{F_S}}$

COST OF PRODUCTION DATA

To compute the economies of scope and scale efficiency gains due to vertical integration, the U.S. level output production and input cost of production data for farrow-to-feeder, feeder-to-finish, and farrow-to-finish for the period 1982-1997 published by Economic Resource Service (ERS) of United States Department of Agriculture (USDA) are used to examine the efficiency gains due to vertical integration. The input and input data for farrow-to-feeder, feeder-to-finish, and farrow-to-finish is available on per cwt basis. The per cwt cost of production data aggregated to variable cost, capital cost, land cost, labor cost and other cost are used as inputs. The variable cost is the sum of the variable cash expenses, general farm overhead, taxes and insurance and unpaid labor in dollars per acre. The capital cost includes capital replacement, operating capital and other nonland capital in dollars per acre. Other costs include general farm overhead, and taxes and insurance. Output per cwt is the gross value of production.

These output and inputs are further converted into implicit output and input quantity indexes by deflating with the gross domestic product implicit price deflator. A single output and five inputs from 1982 to 1997 are used to compute the economies of scope and scale efficiency gains due to vertical integration.

EMPIRICAL APPLICATION AND RESULTS

To examine the economies of scope efficiency gains (equation 10), scale efficiency gains (equation 11) and overall efficiency gains (equation 12) due to vertical integration, the input distance functions defined in equations (6 and 7) are estimated. Table 1 presents the average output and input variables employed in the analysis. The average and rate of change in overall technical efficiency $D_i(y,x|CRS)$ defined as a product of pure technical efficiency $D_i(y,x|VRS)$ and scale efficiency $S_i(y,x)$ for farrow-to-feeder, feeder-to-finish, and farrow-to-finish estimated utilizing the input distance function defined in equation (5) is presented in Table 1.

The average overall technical efficiency (of 0.857, 0.980 and 0.907) is more explained by pure technical efficiency (of 0.942, 0.995 and 0.970) compared to scale efficiency (of 0.914, 0.985 and 0.935) for farrow-to-feeder, feeder-to-finish, and farrow-to-finish hog sector. Results from Table 1 indicate the importance of pure technical efficiency and the scale efficiency on overall technical efficiency. The three efficiency measures between 1982-1997 indicate a positive; zero and negative rate of change for farrow-to-finish, farrow-to-feeder, feeder-to-finish respectively. The individual technical efficiency, pure technical efficiency and scale efficiency scores of farrow-to-feeder, feeder-to-finish, and farrow-to-finish provide the basis for decomposition of the overall efficiency gains into scope efficiency gains and scale efficiency gains due to vertical integration of hog industry.

SCOPE AND SCALE EFFICIENCY GAINS DUE TO VERTICAL INTEGRATION

The additional insights of the potential influence on structural change due to vertical integration can be carefully conceptualized based on the decomposition of overall technical efficiency gains into scope efficiency gains and scale efficiency gains. The overall efficiency gains, a product of efficiency gains due to scope and efficiency gains due to scale for vertical integration of hog sector is presented in Table 2 for the period, 1982-1997. Results from Table 2 indicate the realization of scope and scale efficiency gains with the exception of 1994 year due to vertical integration of hog industry. However, the negative rate of change in overall efficiency gains (due to economies of scale) between 1982-1997 indicates a decreasing trend in efficiency gains of vertical integration in hog production sector.

The results of the $t-$test examining the null hypothesis that the realized overall, scope and scale efficiency gains for the hog sector is equal to one are presented in Table

2. Based on the test statistic and $p-$value for the $t-$test at the 5% level of significance, this test indicates the mean overall efficiency gains and scope efficiency gains are significantly different from one. Overall, results of the average efficiency gain measures and the $t-$test indicate hog sector experienced vertical integration efficiency gains, a product of the efficiency gains due to economies of scope and scale.

CONCLUSIONS

Utilizing the non-parametric linear programming approach, theoretically and empirically we demonstrate -the overall efficiency gains realized by vertical integration is due to economies of scope efficiency gains and the economies of scale efficiency gains. The individual estimates of the efficiency measures over time indicate the average overall technical efficiency across farrow-to-finish, farrow-to-feeder, feeder-to-finish of 0.915 is contributed equally by the pure technical (0.969) and scale efficiency (0.945). This supports the importance of pure technical efficiency (scope efficiency gains) and the scale efficiency (scale efficiency gains) in explaining the technical efficiency (overall efficiency gains).

This research is directed only at two stages of the entire pork production industry. It includes two production components but not processing/distribution of pork products. Thus, this research is directed at the structural economic forces at vertical integration in hog production only. The research here suggests higher efficiency gains of vertically integrated operations i.e., farrow-to-feeder and feeder-to-finish.

Where data is available the analysis completed here is useful technique in understanding gains from vertical integration. In integration efficiency studies identifying scope and scale impacts, either aggregate or individual firm data can be employed. Bootstrapping techniques can also be employed in association with DEA analysis to provide still greater confidence regarding the conclusion of these analyses. In addition, a larger data set with greater disaggregation of inputs would aid in deriving broad conclusions.

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FIGURE 1. SCOPE AND SCALE EFFICIENCY GAINS DUE TO VERTICAL INTEGRATION

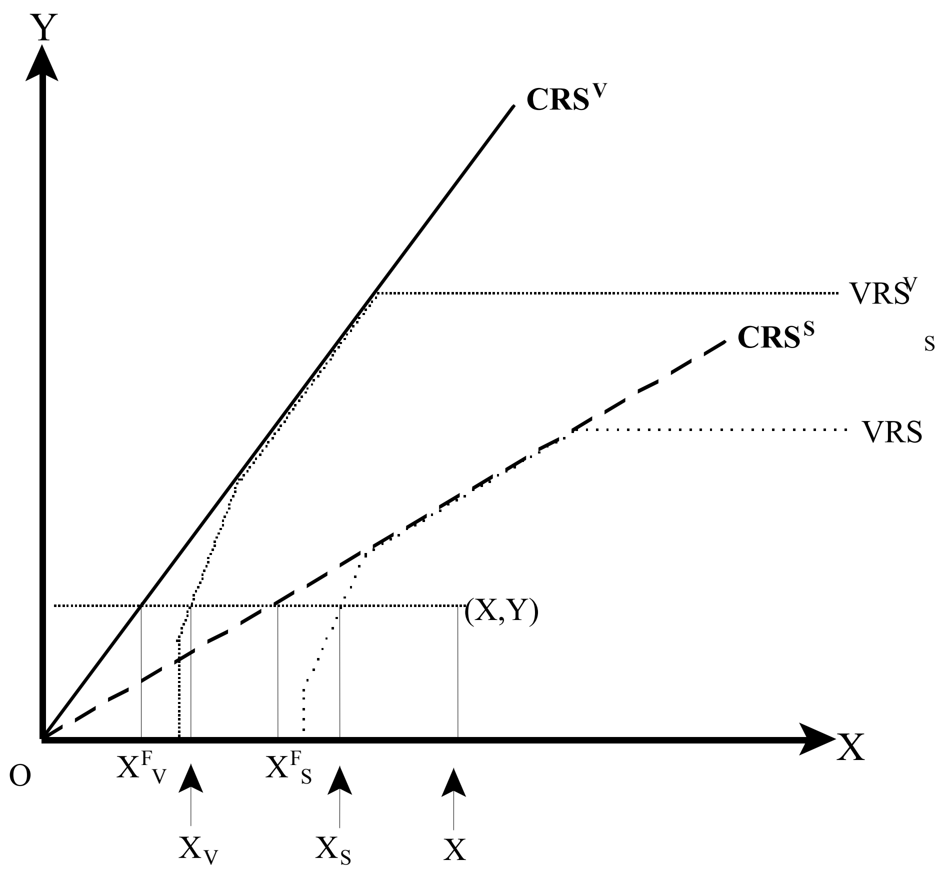

Table 1. Average Output and Input Variables, and Technical, Pure Technical and Scale Efficiency of Farrow-Finish, Farrow-Feeder Pig, and Feeder Pig-Finish for the period, 1982-1997.

Variables	Farrow to Finish	Farrow to Feeder Pig	Feeder Pig to Finish
Production	41.07	66.11	51.74
Variable cost	8.87	24.84	8.03
Capital cost	0.13	0.51	0.07
Land cost	3.87	16.83	3.08
Unpaid labor cost	2.53	7.47	3.37
Other cost	27.82	95.81	63.02
Average Efficiency			
$D_i(y,x\|CRS)$	0.907	0.857	0.980
$D_i(y,x\|VRS)$	0.970	0.942	0.995
$S_i(y,x)$	0.935	0.914	0.985
Rate of Change (ROC)			
$D_i(y,x\|CRS)$	0.145	0.000	-0.245
$D_i(y,x\|VRS)$	0.000	0.000	-0.236
$S_i(y,x)$	0.145	0.000	-0.009

where $D_i(y,x|CRS)$ is the overall technical efficiency computed under the assumption of constant returns to scale, $D_i(y,x|VRS)$ is the pure technical efficiency computed under the assumption of variable returns to scale, $S_i(y,x)$ is the scale efficiency computed under as the ratio $D_i(y,x|CRS)$ over $D_i(y,x|VRS)$, and ROC is the rate of change over the time period, 1975-1996 computed as $\sqrt[T]{X_{t=T}/X_{t=1}}*100$

Table 2. Scope, Scale and Overall Efficiency Gains due to Vertical integration, 1982-1997

Year	Overall *	Scope *	Scale *
1982	1.089	1.000	1.089
1983	1.313	1.024	1.282
1984	1.198	1.000	1.198
1985	1.191	1.000	1.191
1986	1.000	1.000	1.000
1987	1.000	1.000	1.000
1988	1.015	1.000	1.015
1989	1.130	1.048	1.078
1990	1.000	1.000	1.000
1991	1.057	1.047	1.009
1992	1.049	1.000	1.049
1993	1.160	1.132	1.025
1994	1.082	1.093	0.990
1995	1.186	1.185	1.001
1996	1.000	1.000	1.000
1997	1.064	1.000	1.064
Aver	**1.0958**	**1.0331**	**1.0619**
ROC	**-0.1452**	**0.0000**	**-0.1452**

*Indicates an outcome beyond 5% level of significance for the t-test examining the null hypothesis that the vertical integration efficiency gains, scope efficiency gains and scale efficiency gains is equal to one.